N85-23271

Annual Progress Report

NASA Grant NAG 5-398

Analysis of the Inflow Layer and Air-Sea Interactions in Hurricane Frederic (1979)

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April 1985

1. Introduction

The goal of this project is to perform a detailed analysis of the inflow layer of Hurricane Frederic for the period 11-12 SEP 1979. The core region (0-150 km) has been analyzed by Frank (1984) using a combination of aircraft and surface data. Powell (1982) composited surface data from the center to about 800 km radius. Frank and Rodgers (1984) made a preliminary attempt to integrate satellite-derived wind vectors and rawinsonde data with the other data sets to obtain a continuous analysis from 0-800 km radius at three levels, the surface, 560 m and 1600 m. While the results of the latter study were promising, difficulties in assigning accurate heights to many of the low-level satellite winds significantly degraded the accuracy of the results. Assigning these wind vectors to either the 560 m level or the 1600 m level proved unsatisfactory. Stereo imagery was available for a limited portion of the analysis period, but the vast majority of the low-level satellite winds were determined from single-satellite imagery.

The current study is attempting to overcome the problem of uncertain heights of the satellite-winds by the following methodology:

(1) Vertical profiles of the tangential and radial winds are constructed wherever there are aircraft, surface and/or rawinsonde data available at multiple levels.

(2) The heights of satellite-derived wind vectors measured in the vicinities of these independent vertical profiles are determined by comparison with the profiles.

(3) Plan view analyses of the heights of the satellite-wind vectors are obtained by subjective analysis of the results of (2). Separate analyses are performed for 11 and 12 SEP 79.

(4) In the many regions where satellite-wind vectors represent

the only data source, the satellite-winds are adjusted to the 560 m and 1600 m analysis levels. This is accomplished by using the heights of the wind vectors (step 3) and observed vertical wind variations from the nearest multiple-data-level locations.

The central hypothesis being explored by the above analysis procedure is that the heights of satellite winds and vertical wind shear patterns vary less in the horizontal than to the winds themselves. If this were not true, then all of the satellite wind vectors would be of little or no value since the significant vertical shear of the radial wind in the inflow layer would result in large inaccuracies in estimates of radial flow.

2. Objectives

The specific objectives of this study are to:

- Determine the effective heights of the satellite wind vectors.
- Integrate satellite, aircraft, rawinsonde and surface wind measurements into a three dimensional analysis of the storm inflow layer over water.
- Construct similar analyses of the thermodynamic fields in the inflow layer.
- Perform diagnostic budget analyses of moisture, sensible heat, kinetic energy and momentum in the inflow layer.
- Examine air-sea interactions from residuals in the budget analyses.

3. Significant Accomplishments

During the first year of the project, the primary achievement was the completion of the task of data processing. The data set consists of rawinsonde, aircraft, surface and satellite wind vector data. These four combined sources reflect the atmospheric conditions which were present over the Gulf of Mexico and the contiguous land masses during the 41 hour period beginning at approximately 1100 GMT on 11 SEP 1979 and terminating at 0400 GMT 13 SEP 1979. After eliminating those data which were found to be inconsistent with neighboring values, a final data set consisting of 64 rawinsonde soundings, 177 aircraft data points (30-second averages), 237 satellite wind vectors and 198 surface reports was compiled.

All of the data were plotted in storm relative coordinates. It was found that the vertical and horizontal distribution of data from each individual source was highly variable.

The rawinsonde data provided excellent vertical resolution, although the horizontal distribution was rather poor. Eight data levels extending from the surface to 500 mb were extracted from each rawinsonde sounding. The height of each level was calculated using the hypsometric equation, and the 850 mb, 700 mb and 500 mb heights were compared to those plotted on conventional NMC upper air charts. The depth of the Planetary Boundary Layer (PBL) was estimated by examining the moisture and temperature profile of each sounding. Since the rawinsondes were all launched from land stations, only data from levels above the PBL were considered. The horizontal distribution of rawinsonde data was asymmetric about the storm center with a minimum of data coverage existing south-west of the storm center. All rawinsonde data used fell between 300-1000 km radius from the storm's center.

The vertical resolution of the aircraft data was quite variable, while the horizontal resolution was minimal. In regions where there were flights at different levels, the resolution was naturally superior to those areas where there was only data at a single level. The elevation of each data point was determined by the radar altimeter. While the aircraft elevation varied, no aircraft datum used had an elevation in excess of approximately 1700 m or less than 250 m. Moreover, the majority of the data were clustered near 600 m and 1600 m. The horizontal distribution of aircraft data was relatively symmetric about the storm center with all data points falling between 150-275 km radius. (This does not include the core data used in the Frank (1984) composite.) Surface ship and buoy data were at the 10 m level and were distributed throughout most portions of the storm.

The horizontal distribution of the satellite wind vectors was rather uniform, and all of the satellite winds used in this study were between 150-1000 km from the center of Frederic. Satellite wind vectors over land were not used so that land induced-friction could not contaminate the wind fields.

To aid in determining the heights of satellite wind vectors, radial and tangential winds and inflow angles were calculated in storm relative coordinates at each data point. The resulting values were divided into two groups such that the winds and inflow angles obtained on 11 SEP (period 1) were separated from those obtained from data on 12 SEP and early 13 SEP 1979 (period 2). This procedure was employed to minimize smoothing of small scale or transient features in the wind field. It will become apparent after further discussion below, that the preservation of the small scale kinematic structure of Frederic is imperative to the successful determination of satellite wind vector heights.

In addition to completing the above data analysis tasks, we have also obtained the available stereo-imagery analyses and a copy of Powell's (1982) boundary layer model. These are being used to assist in determining the heights of the wind vectors (see below).

4. Current Tasks

At the present time, subjective and objective analysis techniques are being used to determine the heights of the satellite wind vectors. The first step consists of objectively analyzing the tangential, radial and inflow wind components separately in limited regions. This procedure is carried out independently for the data from period 1 and period 2 using a Cressman objective analysis scheme. The analysis grid measures 2730 km in the north-south direction and 2030 km in the east-west direction, and the grid spacing is 70 km. The purpose of this initial objective analysis is to smooth data in local areas only.

The radius of influence, number of passes and the degree of smoothing being employed in the initial objective analysis are somewhat unconventional. Typically, the initial radius of influence chosen is approximately 1.6 to 1.8 × the grid spacing; however, an initial radius of 1.4 × the grid spacing of 75 km is currently being employed. The number of passes used when objectively analyzing data is normally a function of the initial radius of influence of the data spacing. In the objective analysis scheme used in the Penn State Mesoscale Model, for example, the initial radius of influence is decreased by 30% for each scan until the radius is approximately equal to the grid spacing. If this criteria were applied to the initial radius of ≃ 105 km used in this study, two passes would have been used. However, three and four passes are being used in this study. Finally, no large-scale smoothing of the objectively analyzed fields is employed in this study. The methodology described above is designed to preserve small scale features in the radial, tangential and inflow fields and to avoid smoothing over large areas.

In the second step used in determining the heights of the satellite wind vectors, subjective analysis techniques are employed. In areas where there is multiple-level data coverage, the satellite-wind vector heights are assigned after comparing the radial and tangential winds and inflow angles of the satellite wind vectors to the respective components from the other data sources.

Because multiple-level data do not exist in many areas during either period 1 or period 2, the heights of many satellite wind vectors cannot be assigned directly. To alleviate this problem, satellite wind vector heights from periods 1 and 2 are being combined to obtain a map of satellite wind vector heights, for the 41-hour period beginning 1100 GMT on 11 SEP 1979 and ending at 0400 GMT on 12 SEP 1979. We are assuming that although the wind velocity of a given satellite wind vector may change from period 1 to period 2, the height of that same wind vector is less variable over the same time period. That is, the heights of the satellite wind vectors are assumed to be more conservative than the values of their wind components or inflow angles.

5. Remaining Work

The heights of all satellite-derived wind vectors will be estimated within the near future. We will then proceed to the remaining tasks:

- Adjust the satellite winds to the primary analysis levels.
- Perform the integrated three-dimensional analysis of the inflow layer kinematic fields using a cylindrical coordinate compositing technique.
- Determine the inflow layer thermodynamic fields.
- Perform diagnostic budget analyses of moisture, sensible heat, kinetic energy and momentum.
- Examine air-sea interactions, including surface stresses and heat and moisture fluxes as budget residuals.
- Synthesize findings and publish the results.

6. Publications

Frank, W.M. and E.B. Rodgers, 1984: Kinematic analysis of Hurricane Frederic (1979) using satellite, aircraft and rawinsonde data. Final Report on NASA Grant NAG 5-102.

7. References

Frank. W.M., 1984: A composite analysis of the core of a mature hurricane. Mon. Wea. Rev., 112, 2401-2420.

Frank, W.M. and E.B. Rodgers, 1984: Kinematic analysis of Hurricane Frederic (1979) using satellite, aircraft and rawinsonde data. Final Report on NASA Grant NAG 5-102.

Powell, M.D., 1982: The transition of the Hurricane Frederic boundary-layer wind field from the open Gulf of Mexico to landfall. Mon. Wea. Rev., 12, 1912-1932.